RETROFITTING VISUAL-LIQUID-FLOW-LABORATORY TRAINER FOR FLUID-MECHANICS STUDIES: A BENCH-SCALE-PROJECT INNOVATION.

George C. Oguejiofor, and Tochukwu O. Nwokeocha
Department of Chemical Engineering, Nnamdi Azikiwe University, Awka.
E-mail: oguejioforg@yahoo.com

ABSTRACT

The strive towards teaching equipment sufficiency in the Faculty of Engineering, Nnamdi Azikiwe University, Awka,Nigeria motivated the retrofitting of the viable teaching equipment constructed by engineering students. In this paper, the visual-liquid-flow-laboratory trainer is described. Also, the teaching capabilities of the various components of the test-pipe of the trainer are carefully reviewed with regard to fluid-mechanics phenomena. Retrofitting is the main focus of this paper. The velocity-head and equivalent-diameter approaches are available for the retrofit-design calculations. This work employs the velocity-head approach as the computations will show. Based on the estimations, the equipment is retrofitted with electric-driven pump and tank. It is piped according to the retrofit scheme and piping arrangement. Also, it is wired and painted. Finally, it is leak-tested and commissioned. The costs of the materials used for the retrofitting of the equipment are accumulated and shown in this report. Interestingly, this retrofitting work proved to be a self-help and inward-looking innovation at the bench-scale level. It is hoped that when deployed for teaching, the bench-scale trainer will enhance practical-pedagogic value.

Keywords: bench-scale level, design estimations, fluid-mechanics phenomena, pedagogic capabilities, retrofitting, velocity-head approach.

NOTATION

Symbols	Description	Units
A_a	The maximum cross sectional area of the float in a horizontal plane	m^2
A_b	The cross sectional area of rotameter annulus	m^2
A_{bb}	The cross sectional flow area at the smooth 90° bend	m^2
A_f	The cross-sectional area of the float	m^2
A_1	The upstream cross sectional flow area before the constriction	m^2
A_2	The point of minimum cross sectional flow area	m^2
C_D	The coefficient of discharge for orifice, venture or rotameter	–
D_i	The pipe inside diameter	m
$D_{i,opt.}$	The optimum inside pipe diameter	m
f	The friction factor	-
G	The mass flow rate of the liquid	kgs^{-1}
g	The gravitational acceleration	ms^{-2}
H	The head required from the pump	m
H_b	The head loss across the smooth 90° bend	m
H_{fp}	The loss of head due to friction in fittings	m

K	The number of velocity heads	-
L	The entire pipe length in the horizontal direction	m
N	The speed of rotation of the centrifugal pump	rev/sec
N_s	The dimensionless specific speed of pump	-
P_w	The output power of the centrifugal pump	W
Q	The liquid discharge through the centrifugal pump	m^3s^{-1}
Q_{fp}	The liquid flow rate at the discharge pipe	m^3s^{-1}
V	The liquid velocity	ms^{-1}
V_{bb}	The liquid velocity at the smooth 90° bend	ms^{-1}
V_{b2}	The exit pipe velocity	ms^{-1}
V_1	The liquid velocity at station 1	ms^{-1}
V_2	The liquid velocity at station 2	ms^{-1}
W	The work done is transporting liquid through the system	Jkg^{-1}
ρ	The density of the liquid	kgm^{-3}
ρ_f	The density of the material of the float	kgm^{-3}
μ	The liquid viscosity	$mNm^{-2}s$
ΔP	The difference in systems pressures (P_1-P_2)	Nm^{-2}
ΔP_{fp}	The pressure drop due to friction in pipe	Nm^{-2}
ΔP_t	The pressure drop due to friction in pipeline, fittings test pipe and valves.	Nm^{-2}
ΔZ	The difference in elevations ($Z_1 - Z_2$)	m
η	The efficiency of the centrifugal pump	%
V_f	The volume of the float	m^3

INTRODUCTION

One of the active problems facing Nigerian Universities is lack of teaching t and research equipment. This is a challenge to the practical-side of education. The equipment needed for practical education require huge amount of money which many Nigerian Universities cannot afford. For example, one of the cheapest equipment from the 2005 price list of Armfield Technical Education Company, Ltd, UK, is the particle drag coefficient apparatus, which costs ₦2,611,205 [Uhegbu, 2005:4]. ₦2,611,205 is about US $17,919 at an exchange rate of US$1.00 = Nigerian ₦145.72.

Interestingly, the visual-liquid-flow trainer is an equipment constructed by project students. The current retrofitting project will complete the development of the equipment for deployment in practical teaching of fluid mechanics fundamentals. The novelty in this work is all about local improvisation for overcoming the inadequacy of teaching and research equipment needed for enhancing engineering education at Nnamdi Azikiwe University, Awka.

EQUIPMENT DESCRIPTION AND REVIEW OF PEDAGOGIC CAPABILITIES

The visual-liquid-flow trainer is a bench-scale equipment retrofitted to ensure that students who use it are accustomed to devices for pressure drop and flow measurements/calibrations. The equipment consists of the free-standing framework, the test pipe and the instrumentation panel. (See figure 1: the photograph of the equipment before retrofitting.)

The free-standing framework is 1 inch (25.4mm) angle iron, 4ft(1.219m) in length, 2ft(0.610m) in width and 6ft (1.829m) in height. On the frame work is mounted a horizontal plywood measuring 4ft (1.219m) long by 2ft(0.610m) wide, which formed the table; and the vertical board of 4 ft (1.219 m) long by 4 ft (1.219 m) wide, which formed the instrumentation panel. The test pipe is mounted at the corner of the horizontal plywood and the vertical board (instrumentation panel), while the manometers are fitted on the instrumentation panel.

The test pipe is made of borosilicate glass and contains the horizontally fitted flow diffuser (enlarger), the venturimeter and the orificemeter. It also embodies the horizontal-to-vertical 90^o smooth bend, and the vertically-mounted rotameter.

The Flow Diffuser (enlarger)

The flow diffuser consist of a glass upstream pipe of ⅜ inches(9.525mm) diameter, and a downstream pipe of ¾ inches (19.05mm) diameter fused together, with pressure tapping points fitted at the upstream and downstream pipes. For the liquid flow in the diffuser or enlarger, Coulson and Richardson [1999:76] give the theoretical equations for analyzing the change in pressure ($-\Delta P_f$) and the head loss (H_f) as:

$$\Delta P_f = \frac{\rho(V_1 - V_2)^2}{2} \quad \ldots 1$$

and

$$H_f = \frac{(V_1 - V_2)^2}{2g} \quad \ldots 2$$

where:

$$V = \frac{G}{\rho A}$$

These equations express the teaching capabilities of the flow-diffuser component of the trainer.

The Venturimeter and Orificemeter

The venturimeter is made up of a short length of 8^o to 10^o convergence and a longer length of 3^o to 5^o divergence, with two pressure tappings provided at the tip of the converging cone and the throat. The diameters of the pipe before the convergence and after the divergence are ¾ inches (19.05mm), while the diameter of the throat is ⅜ inches (9.525mm).

The orificemeter is made up a ¾ inches(19.05mm) diameter pipe fitted with a circular plate having a 9mm bore in its centre, such that the upstream and downstream pipe diameters are 19.05mm, while the constriction (vena contracta) is 9mm in diameter. Pressure tappings are fixed at a distance of one diameter upstream the orifice plate and the other at a distance of half a diameter downstream the plate.

For the incompressible (ρ = constant) and inviscid (μ=0) liquid flow in the orificemeter and venturimeter, Kumar [2007:231] gives the theoretical expression for determining the liquid velocity at the vena contracta and throat as:

$$V_2 = \frac{A_1}{\sqrt{A_1^2 - A_2^2}} \sqrt{2g\left[\frac{P_1 - P_2}{\rho g} + (Z_1 - Z_2)\right]} \quad \text{... (3)}$$

The expression for actual discharge ($Q = C_D V_2 A_2$) through a horizontal orificemeter and venturimeter where $Z_1 = Z_2$, $P_1 = \rho g h_1$ and $P_2 = \rho g h_2$, eqn(3) becomes:

$$Q_f = C_D \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2g(h_1 - h_2)} \quad \text{...(4)}$$

where according to Kumar[2007:233]

$$A_1 = \frac{\pi}{4} D_1^2; \qquad A_2 = \frac{\pi}{4} D_2^2$$

and $$\frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} = \frac{\pi}{4} \frac{D_1^2 D_2^2}{\sqrt{D_1^4 - D_2^4}}$$

For the venturimeter, the value of C_D lies from 0.95 to 0.98; while for the orificemeter, the value of the C_D varies from 0.60 to 0.65 [Kumar, 2007:234].
Eqn (4) describes the analytical formula for orifice and venturi metering applicable to the visual-liquid-flow trainer and this expresses the teaching capabilities of the orifice and venture components of the trainer.

The Horizontal-to-Vertical 90^o Smooth Bend

The 90^o smooth bend consists of ¾ inch (19.05mm) diameter pipe that changes flows from horizontal to vertical direction, with the curvature that approximates to 90^o standard elbow. Pressure tappings are fixed at the horizontal and vertical sides of the bend.
In terms of inlet velocity head (K), the head loss around a 90^o smooth bend, or fittings in a pipe is presented by Kumar [2007:387] by specifying the number of velocity heads (K) such that:

$$H_b = \frac{K V_{bb}^2}{2g} \quad \text{...(5)}$$

where:

(a) Average velocity in the pipe bend = $V_{bb} = \frac{Q}{A_{bb}}$

(b) According to Kumar [2007:388] the value of K = 1 for an elbow (90^o bend) at the reference velocity V_b.

However, in terms of equivalent length L_e of the pipeline, Kumar [2007:387] expresses the head loss around a bend as:

$$H_b = f\frac{L_e}{D_i}\frac{V_{bb2}^{2}}{2g} \qquad \text{... (6)}$$

or

$$K = f\left(\frac{L_e}{D_i}\right) \qquad \text{... (7)}$$

where: the number of equivalent pipe lengths, L_e = 30 – 40 for a 90^o elbow [Sinnott, 1999: 203].

Eqns (5), (6) and (7) describe the analytical formulae for the experimental evaluation of liquid flow through the 90^o bend in the test pipe of the visual liquid flow trainer. Users of the trainer would accustom to the practical use of these equations and these are the highlights of the pedagogic capabilities of the trainer.

The Vertically-mounted Rotameter

The rotameter is 250mm long with a diameter of 25.4mm at the top and 20mm at the bottom. It contains a brass float 19mm in diameter and volume of 6.0cm^3

For an incompressible fluid flow in a rotameter, Coulson and Richardson [1999:228] define the mass flow rate as:

$$G = C_D A_b \sqrt{\frac{2gv_f(\rho_f - \rho)\rho}{A_f\left[1-\left(\frac{A_b}{A_a}\right)^2\right]}} \qquad \text{...(8)}$$

where the values for C_D can be obtained from Figure 6.19 of Coulson and Richardson [1999:230] for various rotameter shapes and Reynolds number through annulus. Eqn (8) expresses the teaching capability of the rotameter component, and this would enable users to internalize the practical application of the equation.

The Instrumentation Panel

The instrumentation panel is fitted with a bank of four inverted u-tube differential manometers and one vent tube. The range of these manometers is 0 – 440mm of water differential. By means of 6mm tubing, each of the limbs of the bank of four u-tube manometers is connected respectively to the tapping points fitted on the diffuser, ventrimeter, orificemeter and 90^o bend. The result is that the pressure differential ($h_1 - h_2$) between the two tappings on the diffuser, venturimeter, orificemeter and 90^o bend can be measured separately by means of the inverted u-tube manometer on which the tappings are connected; and evaluated by the expression:

$$\Delta P_f = \rho g(h_1 - h_2) \qquad \text{...(9)}$$

Users of the instrumentation panel would accustom to the practical use of eqn (9) and this explains the pedagogic capability of the trainer.

REVIEW FOR EQUIPMENT RETROFITTING

The literature review focuses on the considerations for the selection of retrofit devices such as the circulation pipe system and the centrifugal pump.

Sizing the pipe required for retrofit

The following simplified equations is presented by Peters and Timmerhaus [1981:525] for making design estimate for pipe size:
For turbulent flow (Re>2100) in steel pipes:

$$D_{i,opt} = 3.9Q_{fp}^{0.45}\ \rho^{0.13} \qquad \text{...(10)}$$

In steady incompressible flow in a pipe, the losses are expressed in terms of a pressure drop (ΔP_{fp}), or a head loss (H_{fp}). The pressure drop in a pipe, ΔP_{fp} due to friction is given by Sinnott [1999:200] as:

$$\Delta P_{fp} = 8f\left(\frac{L}{D_i}\right)\frac{\rho V^2}{2} \qquad \text{...(11)}$$

where according to Anderson et al [1976:38] for lamina flow,

$$f = \frac{64}{Re} \qquad \text{...(12)}$$

Eqns (10), (11) and (12) will be used for designing the retrofit piping.

Sizing the Centrifugal Pump required for Retrofit

To ensure the satisfactory selection of the centrifugal pump required to circulate water through an entire system, the energy required by the pump, the total head required, and the output power of the pump are taken into considerations.

Sinnott [1999:205] gives the equation for calculating the total energy required by the pump for transporting fluid through the system as:

$$g\Delta z + \frac{\Delta P}{\rho} - \frac{\Delta P_t}{\rho} - W = 0 \qquad \text{... (13)}$$

where the variables are defined in the Notation Section. If W is negative a pump is required.

The head required from the pump (H) is also given by sinnott [1999:205] as:

$$H = \frac{\Delta P_t}{\rho g} - \frac{\Delta P}{\rho g} - \Delta Z \qquad \text{...(14)}$$

The power required by the pump (Pw) is given by sinnott [1999:205] as:

$$P_w = (W \times G)/\eta \qquad \text{... (15)}$$

Or

$$P_w = (WQ_{fp}\ \rho)/\eta \qquad ...(16)$$

Alternatively, Kumar [2007:498] presents that the output power of a power generating machine operating with an efficiency η is given as:

$$P_w = \rho g Q_{fp} H.\ \eta \qquad ...(17)$$

where all the symbols are defined in the Notation section Eqns (13), (14), (15), (16), and (17) will be applied in determining the parameters for sizing and specifying the centrifugal pump that is required for retrofitting into the visual-liquid-flow-experimentation apparatus.

Also, centrifugal pumps are characterised by their specific speed. In the dimensionless form, specific speed is given by sinnott [1999:199] as:

$$N_s = \frac{NQ^{1/2}}{(gH)^{3/4}} \qquad ...(18)$$

Kumar [2007:500] classifies the dimensionless specific speed N_s as follows:

Class	**Specific Speed (N_s)**
Low Specific Speed	Less than 0.3
Medium Specific Speed	0.3 to 3.0
High specific Speed	3.0 to 30

Eqn (18) will be applied in computing the specific speed of the centrifugal pump to be retrofitted into the visual liquid flow experimentation apparatus.

MATERIALS AND METHODS OF RETROFITTING

The scope of materials and methods covered the processes of design calculations, fitting and piping, wiring and costing of retrofitting materials.

Design Computations

The retrofitting started with the calculations of the parameters that described the sizes, specifications and characteristics of retrofit devices, namely the pipe and the pump. Table 1 shows the summary sheets for the design computations whose details are displayed in sections 1 through 8 in the Appendix.

Fitting and Piping

Based on the specifications in Table 1 the following materials were procured; one 340 watts centrifugal pump with 1 inch inlet and delivery diameters respectively, one 30 litre plastic tank, eight 1 inch PVC elbows, three 1 inch PVC adaptors, two 1 inch PVC union and couplings, two 1 inch PVC plug valves, one 1 inch PVC socket, one 1 inch PVC backnut and 490cm of 1 inch PVC pipe.

The pump and tank were retrofitted on the bottom platform of the free-standing framework. With the various fittings the equipment was piped according to the arrangement shown in Figure 3.

To ensure that the manometers are activated by pressurization, one of the plug valves coded CV1 was mounted upstream before the test pipe (see Figure 3). The other valve coded CV2 was mounted downstream after the test pipe for the purpose of flow control.

Wiring
Using the 13Amps plug and socket with indicator pilot lamps and three core 1.5mm^2 flexible cable, the centrifugal pump was electrically wired. The retrofitting was completed with the labelling and painting of the apparatus. Figure 2 shows the photograph of the apparatus after the retrofitting. The apparatus is ready for experimental evaluation and appraisal.

Costing of Retrofitting materials.
The total cost of the materials used for the equipment retrofitting was ₦11,625 (US$79.75) and Table 2 shows the schedule of the costs of the direct materials used in the project work.

DISCUSSION
Pump Workload and Sizing
To Transport water from tank to the test pipe through the pipeline (refer to Figure 3) energy has to be supplied to:

(a) Overcome the friction losses in the pipes.
(b) Overcome the miscellaneous losses in the pipe fittings (elbows, valves, union connectors, backnuts, etc).
(c) Overcome the losses in the test pipe consisting of flow diffuser, orifice meter, venturemeter, 90^o bend and rotameter
(d) Overcome the difference in elevation from end to end of the pipe and which in this case in Δz = -0.98m (see Figure 3).

The estimation of energy requirement (W) for overcoming the above-listed losses produced a negative value, which indicated that a pump was required (Refer to Table 4). Subsequently, the capacity of the pump required was estimated from two approaches, namely the Sinnott [1999:205] approach represented by eqn(16) and the Kumar [2007:498] approach represented by eqn (17). Interestingly the results obtained form both approaches were consistent as shown in Table 4.

Pedagogic Capabilities
The theoretical equations governing liquid flow through and in the diffuser, venturimeter, orificemeter, 90^o bend and rotameter were described and presented as eqns (1), (2), (3), (4), (5), (6), (7), (8) and (9) respectively. This implied that the visual-liquid-flow-laboratory

trainer has multiple pedagogic capabilities as shown by eqn (1) through eqn (9). These equations will be made active and practical for users when the trainer is employed for hands-on training of engineering students at Nnamdi Azikiwe Unibversity, Awka, Nigeria. It is likely the laboratory trainer will enable users to practically accustom themselves to eqn (1) through eqn (9), rather than the use of hypothetical data and examples in theoretical teaching, which no doubt make learning passive.

CONCLUSION

This equipment retrofitting project is an inward-looking and self-dependent approach aimed at tackling teaching equipment problem at the Faculty of Engineering, NAU, Awka. In this regard, the visual-liquid-flow trainer has been successfully retrofitted to completion as shown in Figure 3, and the trainer is now ready for experimental evaluation and appraisal. It is expected that the trainer will prove useful for engineering pedagogy.

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APPENDIX

Table 1: Summary Sheet for Design Computations

Fluid type: water

A) Pipe sizing for Retofit Application

Design Variables	**Symbol**	**Design Data**
Temperature	T	30^oC
Density	ρ	$1000kgm^{-3}$
Viscosity	μ	$0.85 \times 10^{-3}Nsm^{-2}$
Optimum internal diameter	$D_{i,opt}$	$25 \times 10^{-3}m$

Estimated Parameters	**Symbol**	**Estimation Tool**	**Value Obtained**	**Estimation Section**
Minimum discharge rate	Q_{fp}	Eqn(10)	$1.82\times10^{-6}m^3s^{-1}$	See Section 2 of the Appendix
Cross sectional flow area	A	$\frac{\pi D_{i,opt}^2}{4}$	$4.91 \times 10^{-4}\ m^2$	See Section 3 of the Appendix
Minimum water velocity	V	$\frac{Q_{fp}}{A}$	$3.71 \times 10^{-3}\ ms^{-1}$	See section 3 of the Appendix
Minimum Reynolds number	Re	$\frac{\rho V D_{i,opt}}{\mu}$	109.12	See Section 3 of the Appendix
Minimum friction factor	F	Eqn(12)	0.59	See Section 3 of the Appendix

B) Pump Sizing for Retrofit Application

Estimated Parameters	**Symbol**	**Estimation Tool**	**Value Obtained**	**Estimation Section**
Number of Velocity heads	K	See Section 1 of the Appendix	15.33	See Section 1 of the Appendix
Minimum head loss from fittings	H_{fp}	$K\frac{V}{2g}$	$1.08 \times 10^{-5}m$	See Sections 1 & 3 of the Appendix
Pressure loss from fittings	ΔP_v	$\rho g H_{fp}$	$0.106\ Nm^{-2}$	See Section 3 of the Appendix

Pressure loss from pipe friction	ΔP_{fp}	Eqn(11)	5.093 Nm^{-2}	See Section 3 of the Appendix
Total Pressure loss	ΔP_t	$\Delta P_v + \Delta P_{fp}$	5.20 Nm^{-2}	See Section 3 of the Appendix
Static head	ΔZ	$Z_1 - Z_2$	-0.98m	See Section 4 of the Appendix
Work done by pump	W	Eqn(13)	-9.61Jkg^{-1}	See Section 5 of the Appendix
Minimum pump head	H	Eqn(14)	0.981m	See section 6 of the Appendix
Minimum power required	P_w	Eqns (16) & (17)	0.018W	See section 7 of the Appendix
Dimensionless pump characteristics	N_s	Eqn (18)	9.62 x 10^{-4}	See section 8 of the Appendix
Pump class: Low specific speed since $N_s < 0.3$				

Design Estimations for Equipment Retrofitting

Section 1: Estimation of miscellaneous losses in fittings and Valves.

Fitting/Valve	**Quantity**	**Number of velocity heads, K (unit)**	**Number of Velocity heads, K(total)**
Entry Sharp reduction (tank outlet backnut)	1	0.50	0.50
Elbows	8	0.80	6.40
Union and Coupling	2	0.04	0.08
Plug valve, open	1	0.40	0.40
Plug valve, half open	1	4.00	4.00
Exit sudden expansion	1	1.00	1.00
90^o bend (long elbow)	1	0.45	0.45
Sudden enlargement (diffuser)	1	0.75	0.75
Orifice meter (sudden contraction)	1	0.50	0.50
Venturimeter	1	0.50	0.50
Rotameter	1	0.75	0.75
Total K			15.33

Section 2: Estimation of Minimum discharge, Q_{fp}

$D_i = 25 \times 10^{-3}$m; $\rho = 1000$ kgm^{-3}

Eqn(10) applied:

$D_i = 3.9Q_{fp}^{0.45}\rho^{0.13}$

Substituting into eqn (10)

$25 \times 10^{-3} = 3.9(Q_{fp}^{0.45})(1000^{0.13})$

$$Q_{fp} = \sqrt[0.45]{\frac{25 \times 10^{-3}}{3.9(1000^{0.13})}} = 1.82 \times 10^{-6}\,m^3s^{-1}$$

Section 3: Estimation of dynamic head

Cross sectional area, $A = \frac{\pi D_i^2}{4} = \frac{\pi(25 \times 10^{-3})^2}{4} = 4.91 \times 10^{-4}\,m^2$

Minimum water velocity, $V = \frac{Q_{fp}}{A} = \frac{1.82 \times 10^{-6}}{4.91 \times 10^{-4}} = 3.71 \times 10^{-3}\,ms^{-1}$

Viscosity of water (μ) at 30°C = 0.85×10^{-3} Nsm^{-2}

$$\text{Reynolds number, Re} = \frac{\rho V D_i}{\mu} = \frac{(1000)(3.7 \times 10^{-3})(25 \times 10^{-3})}{0.85 \times 10^{-3}} = 109.12$$

Re = 109.12 < 2100, so flow is lamina

For lamina flow, $f = \frac{64}{Re}$: eqn (12) applied:

$\therefore \quad f = \frac{64}{109.12} = 0.59$

A velocity head = $\frac{V^2}{2g}$ and Head loss from fittings (H_{fp}) = $K\frac{V^2}{2g}$

$V = 3.71 \times 10^{-3}$ ms^{-1}; $g = 9.8$ms^{-2}; K = 15.33

A velocity head = $\frac{(3.71 \times 10^{-3})^2}{2(9.8)} = 7.02 \times 10^{-7}$m of water

Head loss from fittings (H_{fp}) = $\frac{15.33(3.71 \times 10^{-3})^2}{2(9.8)}$ = 1.08×10^{-5} m of water

Pressure loss due to velocity head (ΔP_{vh}) $= \rho g H_{fp}$

$= (1000)(9.8)(1.08 \times 10^{-5})$

$= 0.106\ Nm^{-2}$

Pressure loss due to friction in pipe (ΔP_{fp})

$\Delta P_{fp} = 8f\left(\frac{L}{D_i}\right)\frac{\rho V^2}{2}$: eqn(11) applied

$f = 0.59$; $D_i = 25 \times 10^{-3}m$; $\rho = 1000kgm^{-3}$; $V = 3.71 \times 10^{-3}ms^{-1}$;
$L = 392cm$ or $3.92m$

$$\Delta P_{fp} = (8)(0.59)\left(\frac{3.92}{25 \times 10^{-3}}\right)(1000)\frac{(3.71 \times 10^{-3})^2}{2}$$

$\Delta P_{fp} = 5.093\ Nm^{-2}$

Total Pressure, ΔP_t = $\Delta P_{vh} + \Delta P_{fp}$

$= 0.106 + 5.093$

$= 5.20Nm^{-2}$

Section 4: Estimation of Static head

Maximum difference in elevation, $(Z_1 - Z_2) = 0 - 0.98$

$\Rightarrow \Delta Z = -0.98$

Section 5: Estimation of Energy Balance

Static energy – dynamic energy – work done = 0

$g\Delta z + \Delta P/\rho - \Delta P_t/\rho - W = 0$: eqn (13) applied

$\Delta P/\rho = 0$; $\Delta Z = -0.98m$; $g = 9.8ms^{-2}$; $\Delta P_t = 5.20Nm^{-2}$; $\rho = 1000kgm^{-3}$

Substituting into eqn (13);

$$(9.8)(-0.98) - \frac{5.20}{1000} = W$$

$- 9.604 - 5.2 \times 10^{-3} = W$

Thus $W = -9.61Jkg^{-1}$

Since W is negative a pump is required.

Section 6: Estimation of head required from pump (H)

H = $\frac{\Delta P_t}{\rho g} - \frac{\Delta P}{\rho g} - \Delta Z$: eqn(4) applied

Since $\frac{\Delta P}{\rho} = 0$, therefore,

H = $\frac{5.20}{(1000)(9.8)} - (-0.98)$

$\Rightarrow$ H = 0.981m

Section 7: Estimation of power required from pump (P_w)

Sinnott's formula, $P_w = (WQ_{fp}\rho)/\eta$: eqn (16) applied

Assume η = 1

$P_w = (9.61)\ (1.82 \times 10^{-6})(1000)$

= 0.018 Watts

Kumar's formula, $P_w = \rho g Q_{fp} H$: eqn (17) applied

$P_w = (1000)(9.8)\ (1.82 \times 10^{-6})\ (0.981)$

= 0.018 Watts.

Section 8: Estimation of centrifugal pump Characteristics (Ns)

$N_s = \frac{NQ_{fp}^{1/2}}{(gH)^{3/4}}$: eqn (18) applied

For single stage centrifugal pump N is assumed to be 875rpm

Converting 875rpm to radians per second (Rad.s^{-1});

N = $\frac{875 \times 2\pi}{60}$ rad.s^{-1} = 92 rad.s^{-1}

Substituting into the above eqn (18):

$N_s = \frac{(92)(1.82 \times 10^{-6})^{0.5}}{(9.8 \times 0.981)^{0.75}} = \frac{0.124}{20.44}$ = 0.0061

Since 0.0061 is less than 0.3, the class of the centrifugal pump is low specific speed.

Table 2: Schedule of Costs of Retrofitting materials

Component	**Material specifications**	**Quantity**	**Unit Cost** Nigeria Naira ₦	**Amount** Nigeria Naira ₦	**US Dollar Equivalent**
Rollers	75mm coster rollers with stoppers	4	300	1,200	8.24
Plywood					
	4ft x 0.5ft x 0.042ft of plywood for extension of manometers	1	300	300	2.06
Pump	panel.	1	4000	4000	27.45
	Centrifugal pump of low specific speed, 340 watts, maximum head of 10 meters and with 1				
Tank	inch suction and delivery pipe diameters	1	500	500	3.43
Elbow		8	40	320	2.20
	30-litre PVC cylindrical tank				
Backnut		1	200	200	1.37
	1″ PVC elbow				
Union & Coupling	1″PVC backnut	2	120	240	1.65
Valve	1″ PVC union connector	2	400	800	5.49
Adaptor		3	40	120	0.82
	1″ PVC ball valve				
Socket		2	50	100	0.69
	1″ PVC adaptor				
Adhesive		1	350	350	2.40
	1″ PVC socket				
Pipe		½ length	850	850	5.83
	Tin of Oatey's gum				
On-off Control	1″ PVC pipe	1 each	300	300	2.06
Switch Board	12 Amps socket and plug with pilot lamp indicator	1	150	500	3.43
Wire	0.5ft x 0.5ft x 0.04ft of timber	7 yards	120	840	5.77
Paint			250	500	3.43
	1.5mm^2 3 – coreflex	1	250	500	3.43

	Tin of black paint Tin of Cream paint	1			
	Total			₦11,625	US$79.75
Exchange rate: US$1.00 = Nigerian ₦145.72 as at July 21, 2009.					

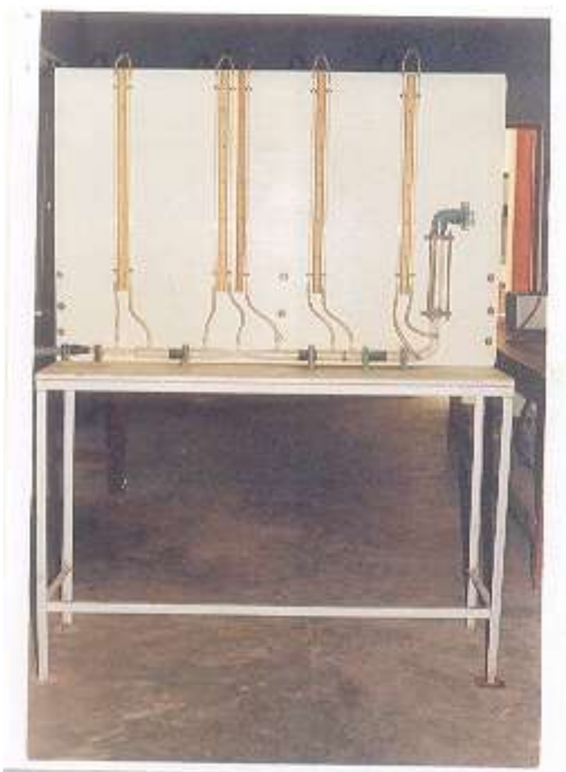

Figure 1: Photograph of the apparatus before the retrofitting

Figure 2: Photograph of the apparatus after the retrofitting.

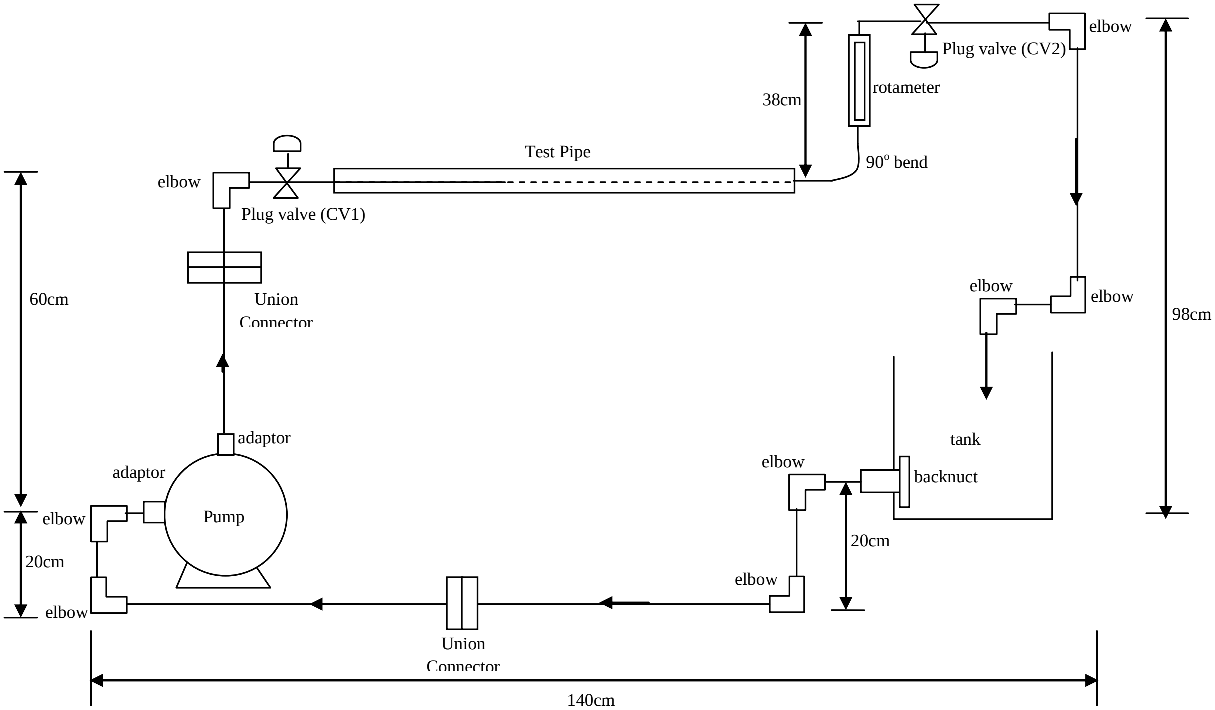

Figure 3: Retrofit Scheme and Piping arrangement